

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

BY

**Keith Russell Edwards
10 Fox Tor Close
Paignton, Devon
TQ4 7SQ**

and

**John Duncan McNicol
Oversteps House
Brixham Road
Kingswear, Dartmouth
Devon, TQ6 ODY**

FOR

A WIRELESS TERMINAL DIVERSITY SCHEME

A WIRELESS TERMINAL DIVERSITY SCHEME

Field of the Invention

5

The present invention relate to wireless communication systems and in particular relates to a wireless terminal diversity scheme on the forward or downlink transmission.

10 Background of the Invention

Presently, in typical mobile cellular radio networks both capacity (maximum number of users) and coverage (area covered from one base station site) tend to be limited by the system uplink (reverse link) performance. This is especially true where either uplink transmitter power is limited (by, *inter alia*, battery life considerations) or interference.

15 Systems employing Code Division Multiple Access (CDMA) techniques with orthogonal downlink (forward link) and quasi orthogonal uplink are generally uplink capacity limited due to other user interference, when users are moving moderate speeds or faster. These

20 CDMA systems employ powerful interleaving and coding to increase and robustness against adverse channel conditions and other user interference. It is, therefore, usual to employ diversity techniques at the base station receiver (uplink) but not on the down link. With the advent of third generation (3G) wireless communications systems i.e. IMT 2000 family members comprising

25 CDMA (both direct spread and multicarrier) and TDMA technology and with mobile data also carried over upgraded existing networks, it is anticipated that more capacity will be required in the downlink rather than the uplink (due to data asymmetry). Similar data symmetry issues will arise in fixed wireless access system terminals, although very much higher power transmitters in

5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

fixed access terminals is possible than compared with mobile hand portables (e.g. 2 watts compared with 200 milliwatts). Since fixed wireless access terminals are usually mains powered with a battery backup provided by larger electrical cells than would be viable to put into a handset or other portable
5 terminal. Additionally fixed wireless access terminals can be fitted with remote handsets or user interfaces and antennas positioned either externally or some distance from the users head/body

Since fixed wireless access terminals are static or move infrequently, for example, between the rooms of a subscribers residence, some of the techniques applied to mobile down links, such as interleaving, are relatively ineffective. In these cases down link capacity and coverage can potentially be the limiting factors in deployment. Diversity techniques are well established and known to help this situation but have generally been considered too complex to implement in a low cost terminal. US-A-548 301 (Nortel Networks Corporation) provides a diversity scheme for base stations with several antennas. This arrangement only processes the outputs from receive antennas which contribute to the overall carrier to noise ratio. This arrangement comprises phase rotators and continually monitors received power levels which results in a moderately complex system suitable for base stations having a large number of antennas.

Object of the Invention

25 It is an object of the invention to provide a low cost and simple to implement radio link diversity arrangement for a wireless terminal.

Statement of the Invention

30 In accordance with a first aspect of the invention, there is provided a wireless subscriber terminal comprising a diversity antenna arrangement and a receive path including signal assessment means, a combiner, switches and control means; wherein, in operation, receive signals are switched in and out of the
35 received path to provide a test combination of received diversity signals for a finite period on a fast switching basis; wherein,

subsequent to an initial selection of receive diversity signals, improvement for a test combination of receive diversity signals is determined by incremental signal quality; wherein, upon determination of an incremental signal quality for said test combination of receive diversity signals are switched into the receive
5 path and under the control of the control means.

Since phase is neither measured nor accounted for, the present invention provides a random search technique and improvement is achieved by selecting antennas to make improvements in bit error rate compared with a
10 non-diverse terminal.

Preferably, the antennas of the system are separated by distance, whereby spatial diversity is employed to differentiate signals. Alternatively, the antennas of the system have a different polarisation, whereby polarisation
15 diversity is employed to differentiate signals. The system could incorporate both spatial and polarisation diversity. A rake receiver is conveniently employed to combine signals which are spatially separated, alternatively, other optimal detection methods could be employed. The delay, T is set to a period corresponding to a chip period to minimise the possibility of creating a
20 broadband null in the reception pattern under low multipath conditions.

In accordance with a still further aspect of the invention, there is provided a wireless subscriber terminal comprising the receiver diversity arrangement.

25 In accordance with a further aspect of the invention, there is provided a method of operating a wireless subscriber terminal comprising a diversity antenna arrangement and a receive path including signal assessment means, a combiner, switches and control means; wherein diverse signals are received from the antenna arrangement are switched in and out of the receive path to
30 provide a test combination of receive diversity signals for a finer period on a fast switching basis; wherein, upon determination of an increment signal quality for said test combination of receive diversity signals, relative to a previous signal quality, said test combination receive diversity signals are switched into the receive path under the control of the control means; wherein,
35 upon determination of no variants in signal quality relative to a previous signal quality, and the prior combination of receive diversity signals are maintained.

Brief Description of the Figures

In order to allow a greater understanding of the invention, reference shall now be made to the Figures, wherein:

5 Figure 1 shows a typical multi-path, fixed wireless scenario;

Figure 2 shows a first embodiment of the invention;

Figure 2a shows a switch arrangement;

10

Figure 2b shows a flow chart depicting operation of the invention.

Figure 2c shows a CDMA timing sequence.

15 Figure 3 shows a first scenario of operation;

Figure 4 shows a second scenario of operation employing a threshold detector; and

20 Figure 5 shows a possible form of an antenna arrangement to provide receive diversity.

Detailed description of the Invention

25

Embodiments of the present invention are described below by way of example only. These examples represent the best ways of putting the invention into effect that are presently known to the applicant although they are not the only ways in which this could be actioned.

30

Referring now to Figure 1, a typical deployment of a multi-path signal environment fixed wireless system, wherein a subscriber station having a single antenna could remain in a signal null for long periods of time. In this case, because of the existence of a multi-path environment, the reception of the down link orthogonality has been compromised to a "quasi orthogonal" situation.

The maximum capacity of the system, N_u , will then be approximated by:-

In the uplink, $N_u \approx \frac{W/R}{E_b/N_0}$

and;

5 in the forward link (down link), $N_u \approx \frac{W/R}{\alpha E_b/N_0}$ or maximum number of codes,
whichever is the lower

10 where W = Spread Bandwidth (chip rate)
 R = Data rate
 E_b/N_0 = Bit energy spectral density
 α = Orthogonality factor (range: 0 - 1)

15 For quasi orthogonality $\alpha = 1$;
for perfect orthogonality $\alpha = 0$.

Generally the uplink bit energy spectral density (E_b/N_0) required for converting operation will be lower than the down link for the same bit error rate (BER) in
20 the static environment for a typical CDMA system. Thus when orthogonality has been compromised it is essential to reduce the bit energy spectral density required on the downlink.

25 A first embodiment of the invention is shown in Figure 2 and provides a simple to implement downlink diversity scheme. The arrangement 20 comprises two antennas, 22, 24. Each antenna receives a different signal due to the multi-path environment. These signals are then amplified by low noise amplifiers 24 to provide a low noise front end to the receiver, 26. One signal is time delayed by optional delay means 28 by a period τ , where τ is the chip rate or the
30 inverse of the Spread bandwidth which signals are switched as appropriate, to a two-way power combiner, 30, the operation of which is controlled by control means 34. A filter (not shown) is provided to filter out adjacent channel interference. The combiner scheme conveniently employs RAKE receivers and makes use of the ability of RAKE receivers to combine two time delayed
35 multi-paths in an optimal manner. Other arrangements operable to provide a signal metric are possible instead of the RAKE receiver.

Figure 2 does not show band pass filters, A/D converters and FIR filters between the combiner and receiver, as would be known to those skilled in the art.

5 Figure 2a shows a switch state arrangement: inputs from both switches A and
B may be selected independently or together relative to their respective signal
strengths and the level of threshold, T. At the combiner, the signal strength on
both antennas is measured by the signal strength measurement devices and
the switch corresponding to the strongest input selected. The switch on the
10 other antenna is selected if, when the signal from the other antenna is added
to the signal of the first antenna, the overall signal strength (carrier to noise)
would increase. The switching is continuous and rapid. As is known, rapid
switching is said to occur when switching occurs within frames, in contrast to
slow switching, which occurs on a frame-by-frame basis or over a longer
15 period. This is possible because the system employs interleaving and an error
correcting code(s) to recover bit errors which may occur due to variations
within a frame for users with high mobility. A method similar to a combiner
algorithm could be employed, such as the algorithm disclosed in US Patent
US-A-5,842,361 (Nortel Networks Corporation), wherein only signals which
20 contribute to the overall signal-to-noise ratio are utilised. The invention takes
advantage of the fact that, in a fixed wireless access scheme or where users
are limited to slow speed by the nature of the application or other factors fades
occur less frequently and last over a longer time frame than compared with
mobile wireless schemes where subscribers are not restricted in mobility and
25 tend to be fast moving.

The addition of the switch and control elements improves the combiner performance over that of the simple combiner by avoiding the case where one antenna being in a power null would cause up to 3dB loss in sensitivity. By
30 reducing the required bit energy spectral density using diversity both coverage
and capacity are improved.

Referring now to Figure 2b there is shown a flowchart detailing one possible method of controlling the switching of the input signal combinations. At the
35 start up, a new (either random or predetermined) selection of switches is selected. The signal is then passed to a delay and test unit wherein a new test signal combination is tested for a fraction of a frame (typically a quarter of a

frame): the signal quality is determined: if there is an incremental improvement in the signal quality then the new signal combination is selected: if there is no incremental improvement in signal quality then the new signal combination is not selected. After each decision to maintain or select a particular input signal
5 combination, there is a delay, the period of delay being determined by the fast switching speed, typically being of the order of one frame.

Referring now to Figure 2c, a series of CDMA frames are shown for a receiver having two receive inputs, A and B, which may be used singularly or in
10 combination. Input A only was selected prior to time t=1; A plus B was test sampled for a "look through" in the frame proceeding the first CDMA frame shown. At t=2 a test sample is sampled but does not improve output and so is not selected and accordingly no change is effected at t=3, which corresponds to the end of the first frame shown in the diagram. During the second frame
15 shown in the Figure, a sample is made at t=4 A plus B. The signal quality is improved and accordingly at t=5 both A and B signals are adopted for the receive path. At t=6 a test is made of received path B, but no signal improvement is apparent and no change to receiver is made at t=7. Similar results occur when a test is made of receive path A at t=8. Nevertheless at
20 t=10 receive path B provides an improvement over the signal and at t=11, the receive path B is adopted. At t=12, A plus B is tested but does not provide an improvement. At t=14, A is tested, which provides an improvement and is adopted at t=15.

25 In a preferred case, where deployment provides low multipath delay spread, a means 36 for evaluating the degree of multi-path (delay spread metric for RAKE) in the environment could be used to disable the selection of the second antenna in the case that orthogonality on the downlink has not been compromised by the channel. If this control was not present the diversity
30 arrangement would compromise orthogonality by adding a multi-path equal in strength to the first path one chip away. This would turn perfect orthogonality ($\alpha = 0$) into compromised orthogonality ($\alpha = 0.5$). In practice, however, this is unlikely to be a drawback in deployment. It is expected that only very few links will have very good orthogonality and the majority will benefit by reduction in
35 Eb/No by more than the any small increase in α introduced by the simplest embodiment.

The range can be increased directly by the lower bit energy spectral density for dB and capacity can be increased by the reciprocal of the bit energy spectral density in linear terms. That is, a 3dB halving of bit energy spectral density increases capacity by up to a factor of 2. By switching only when the second
5 antenna directly contributes to the carrier to noise ratio there is no or little reduction in the signal strength, that is normally associated with this type of diversity when one antenna is in a power null.

Since the fixed channel is generally varying at a slower rate than is
10 encountered in mobile radio situations, the RAKE is not presented with switching transients that would otherwise be present. It is to be noted that if the arrangement includes a simple switch diversity scheme alone, step changes in the RAKE input would be produced, which would be highly undesirable. In such a case, the operation would be similar to the case
15 depicted in Example 1 (Figure 3): A1 begins off largest and then fades whereas A2 begins at an insignificant level and becomes the dominant signal. So at T=0 only A1 is selected. As A2 increases at T=1 it is also selected and both remain selected for T=2 and T=3. Finally at T=4, A1 no longer contributes to C/N and is deselected and only A2 selected.
20

In the second example, shown in Example 2 (Figure 4), two levels of threshold are used to provide hysteresis to the process. This could also be applied in the case of the first example to reduce the impact of change on the RAKE receiver if it was found that two or more signals were present that caused
25 frequent switching. Depending upon RAKE performance a threshold could be chosen to optimise overall performance.

Figure 5 shows a possible antenna set-up where the orientation of vertical and horizontal antennas is such that space and polarisation diversity techniques
30 can be employed. Other spatial and angular orientations are possible.

The switch mechanism is preferably provided with a dual d.c and FIR filter in order to attenuate adjacent channel interference before signals are detected by the level detector. It would also be possible to switch blindly from one
35 antenna to another, provided the switch was made sufficiently quickly to avoid frame error whereby to measure receive level at each antenna.